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## **SATELLITE/SPACECRAFT PROPULSION**

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# TYPES OF SPACECRAFT PROPULSION

## SOLID ROCKET MOTORS

- Orbit Insertion Maneuvers

## LIQUID ROCKET ENGINES

- Main Propulsion

Orbit Insertion, Trajectory Control

- Attitude Control Propulsion

Stationkeeping, S/C Pointing, Orbit Makeup

## OTHER TYPES

- Hydrazine Resistojets
- Low-Power Arcjets

# SATELLITE/SPACECRAFT MISSIONS

## NASA

- Solar System Exploration
- Earth Observation Satellites (EOS)
- Space Exploration Initiative (SEI)

## COMMERCIAL

- Communications, Relay

## MILITARY

- Observation, Tracking, Relay
- Communications, Global Positioning

# PROPULSION TECHNOLOGY DRIVERS

## PERFORMANCE

- High Temperature Materials, More Energetic Propellant Combinations, High Expansion Ratio Nozzles

## CONTAMINATION CONTROL

- Low Contamination Propellants

## LONG LIFE

- Propellant/Materials Compatibility, Leak-Free Components, Health Monitoring and Control

## REDUCED WEIGHT

- Engine Performance, Dual Mode Operation, Light Weight Components (Tankage)

## RELIABILITY

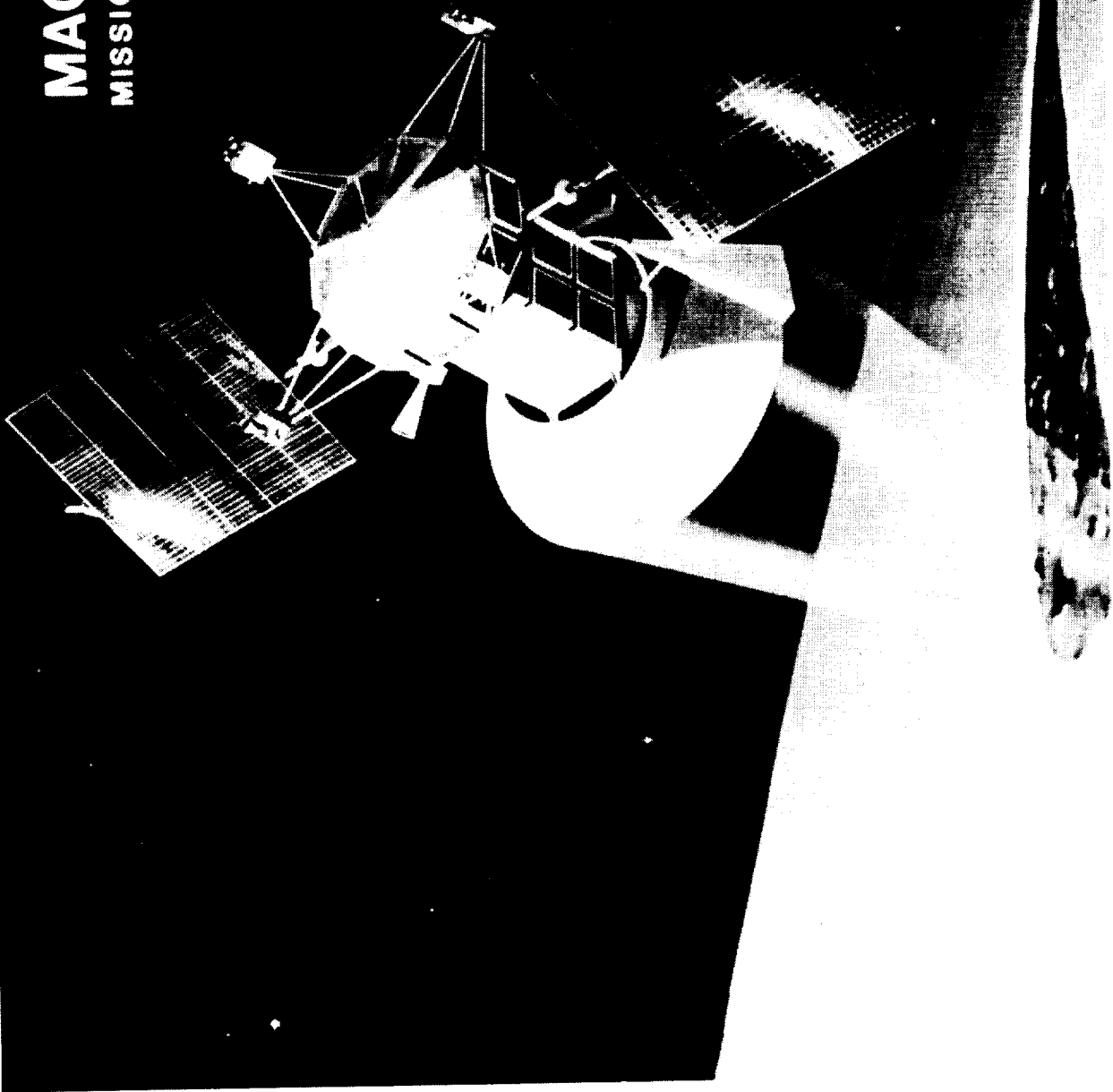
#### MAGELLAN PLANETARY SPACECRAFT

The Magellan spacecraft, launched on 4 May 1989, will gather data needed to understand the surface and interior of Venus. Synthetic aperture radar will penetrate the thick Venusian atmosphere to produce photographic-quality images which will inform us of the geological processes that have acted over time to produce the planet's surface.

The propulsion system for the Magellan spacecraft consists of a solid rocket motor (SRM) for the Venus orbit insertion maneuver and a monopropellant hydrazine system for the remaining propulsive maneuvers. The SRM is a Star 48 motor, built by Thiokol, which will be separated from the spacecraft following the orbit insertion maneuver. The monopropellant hydrazine engines are mounted on four similar rocket engine modules (REM). Each REM includes one 22-N engine, three 0.9-N engines and two 445-N engines. The engines are all built by Rocket Research.

# MAGELLAN

MISSION TO VENUS



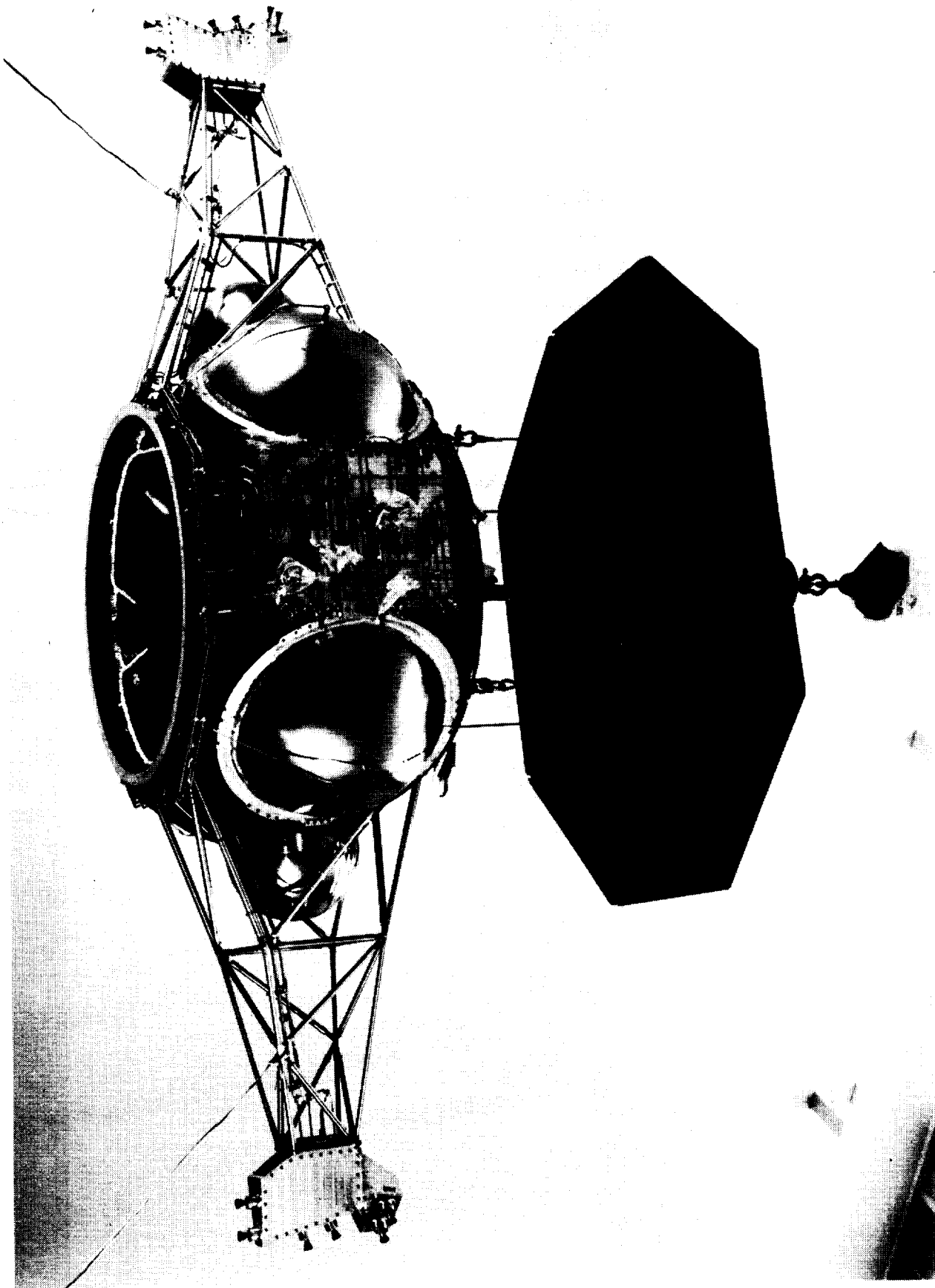
MAGELLAN PLANETARY SPACECRAFT

#### GALILEO PLANETARY SPACECRAFT

The Galileo spacecraft, launched in October 1989, will conduct the first in-depth exploration of the Jovian system. The spacecraft consists of a probe, which will enter the giant planet's atmosphere, and a sophisticated dual-spinning orbiter, which will study Jupiter, its magnetosphere and its major satellites during a 22-month mission.

Bipropellant engines (NTO/MMH), built by MBB, are used for both main and ACS propulsion functions on the Galileo planetary spacecraft. The spacecraft weighs approximately 2500 kg at the beginning of life, with about 38 percent of that weight being propellants. The main propulsion function is accomplished with one bipropellant engine, producing a thrust of 400-N and operating in both steady-state and pulse mode. The ACS propulsion function is accomplished with twelve bipropellant engines, each producing a thrust of 10-N and operating in the pulse mode. It is expected that some of the 10-N engines could experience 20,000 pulses and a total operating time of seven hours during the Galileo mission.

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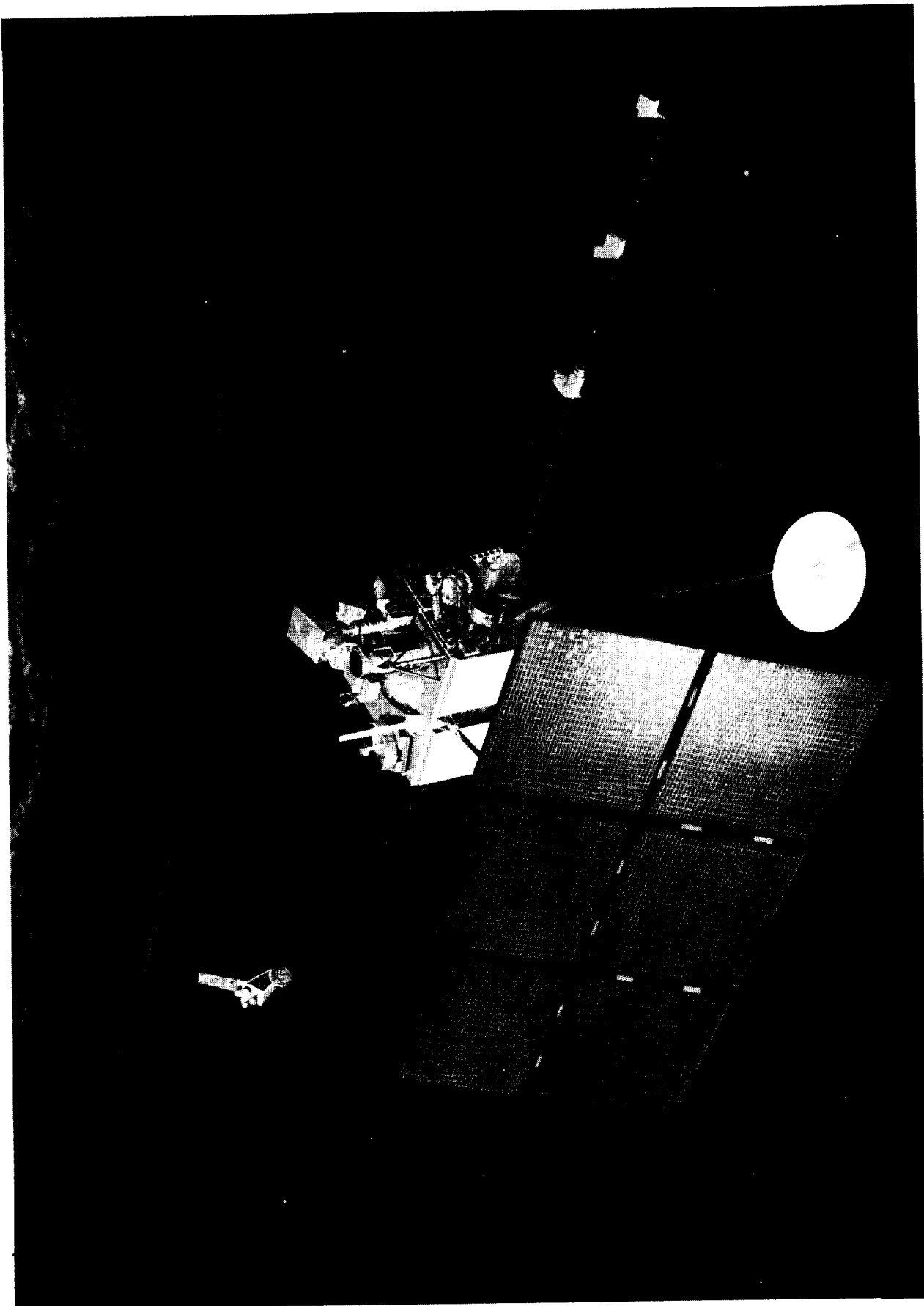
GALILEO PLANETARY SPACECRAFT

#### MARS OBSERVER PLANETARY SPACECRAFT

The Mars Observer spacecraft will be used for the first planetary observer mission. A year after its September 1992 launch, it will enter a low-altitude mapping orbit to make continuous observations of the planet's surface and atmosphere over a full Martian year. The spacecraft instruments will include reflectance, emission and gamma ray spectrometers, a radiometer, an altimeter, a camera, a magnetometer and radio science instrumentation.

The Mars Observer spacecraft will utilize both bipropellant (N<sub>2</sub>O/MMH) and monopropellant (hydrazine) engines. The bipropellant engines, built by Atlantic Research, are planned for the trajectory control maneuvers, orbit insertion and pitch and yaw control. There are four 490-N engines and four 22-N engines in the bipropellant system. The monopropellant engines, built by Rocket Research, are planned for reaction wheel desaturation, orbit trim maneuvers and roll control. There are eight 4.45-N engines and four 0.9-N engines in the monopropellant system. The Mars Observer spacecraft weighs approximately 2500 kg at the beginning of life, with about 57 percent of that weight being propellants.



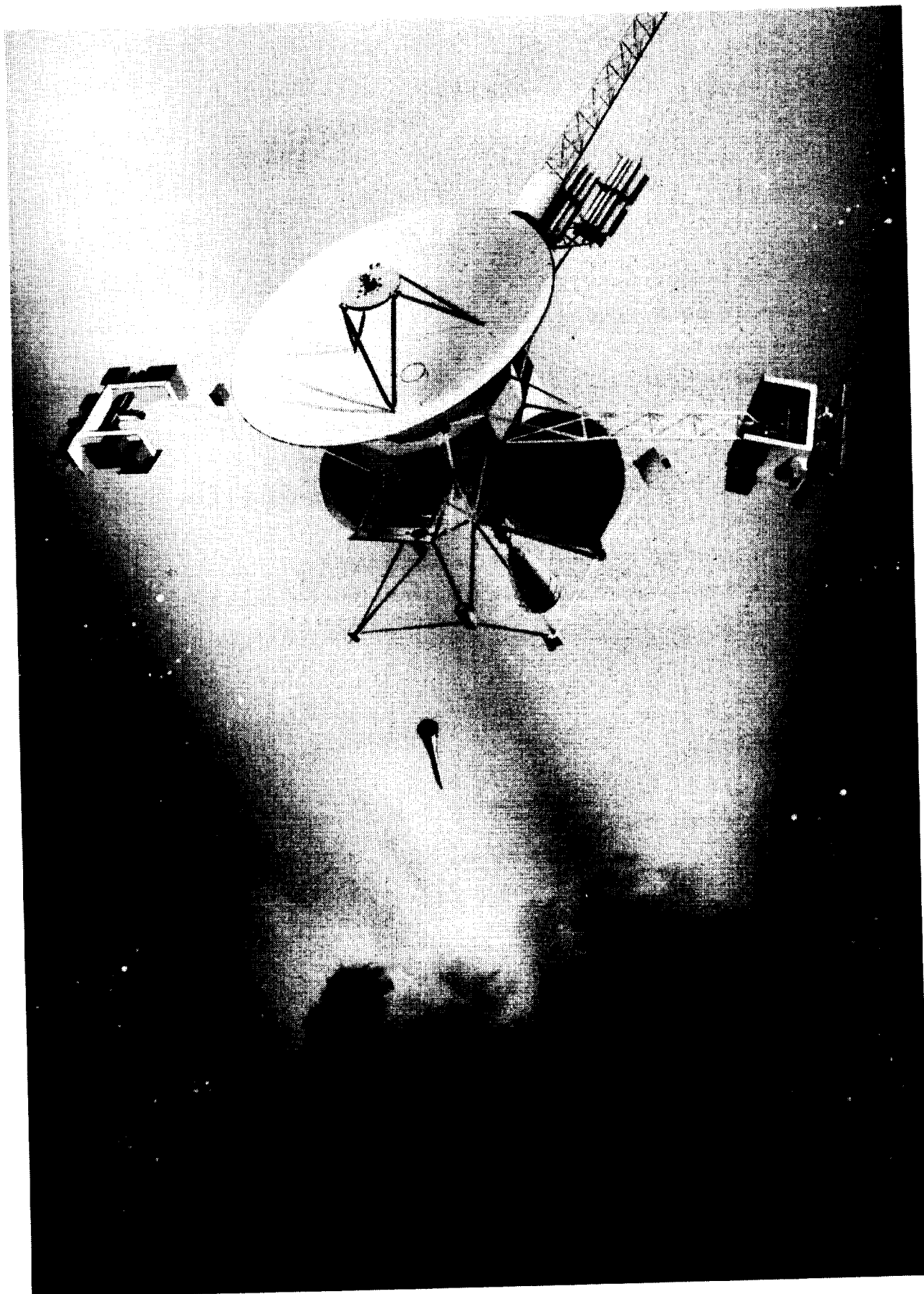


MARS OBSERVER PLANETARY SPACECRAFT

#### CRAF SPACECRAFT

Following its launch in 1995, the Comet Rendezvous Asteroid Flyby (CRAF) spacecraft will fly past one asteroid on its journey to rendezvous with a comet. As the spacecraft accompanies the comet on its orbit around the sun, cameras and instruments will record the onset of comet activity as the comets dirty ice nucleus warms and creates a glowing atmosphere of gas and ions around it.

The CRAF spacecraft will utilize both bipropellant (NTO/MMH) and monopropellant (hydrazine) engines. The single 490-N bipropellant engine is built by Marquardt, while the sixteen 0.5-N monopropellant engines are built by MBB-ERNO. The CRAF spacecraft weighs approximately 5400 kg at the beginning of life, with about 70 percent of that weight being propellants.

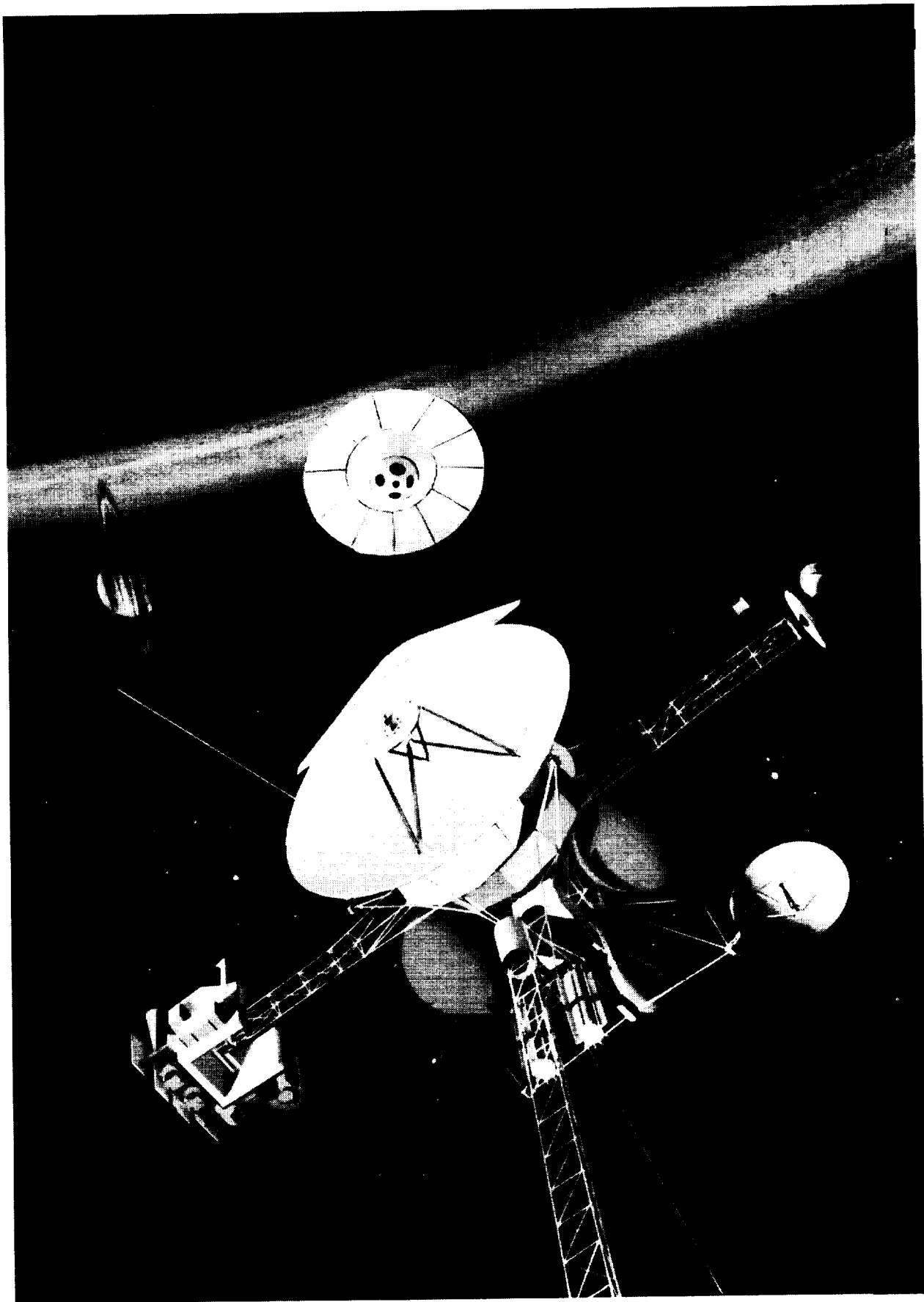


CRAF SPACECRAFT

#### CASSINI SPACECRAFT

The Cassini spacecraft is designed as the second Mariner Mark II spacecraft and is scheduled for launch in April 1996. As a joint NASA-ESA orbiter and probe mission to the Saturnian system, the probe will be delivered to Titan, where it will make measurements of the atmosphere as it descends to the surface. Following delivery of the probe, the orbiter will conduct an intensive four-year investigation of Saturn's atmosphere, ring system, the icy satellites, the magnetosphere, Titan's upper atmosphere and, using an onboard radar, the surface of Titan.

The Cassini spacecraft will be almost an exact duplicate of the CRAF spacecraft, except the propellant load will be reduced by about 300 kg.



CASSINI SPACECRAFT

#### HYDRAZINE RESISTOJETS (TRW)

The electrically augmented hydrazine thruster is an example of a wall-heated thruster. Hydrazine resistojets built by TRW are operational on Ford Aerospace INTELSAT V communications satellites. The INTELSAT V satellite weighs approximately 1170 kg at beginning of life with a solar array power of 1800 W. The INTELSAT uses four hydrazine resistojets for N-S stationkeeping. These resistojets produce a thrust of 0.49 - 0.22 N, an exhaust velocity of 2.9 km/s and require a power input of 550 W - 250 W. Ongoing research at TRW is directed at increased thruster life and performance. Exhaust velocities as high as  $3.3 \times 10^3$  m/s and life in excess of  $2.6 \times 10^3$  Ns have been demonstrated.



# HYDRAZINE RESISTOJETS BUILT BY TRW ARE OPERATIONAL ON FORD AEROSPACE INTELSAT V COMMUNICATION SATELLITES

## INTELSAT V

- 3 AXIS STABILIZED
- 10 YEAR LIFE

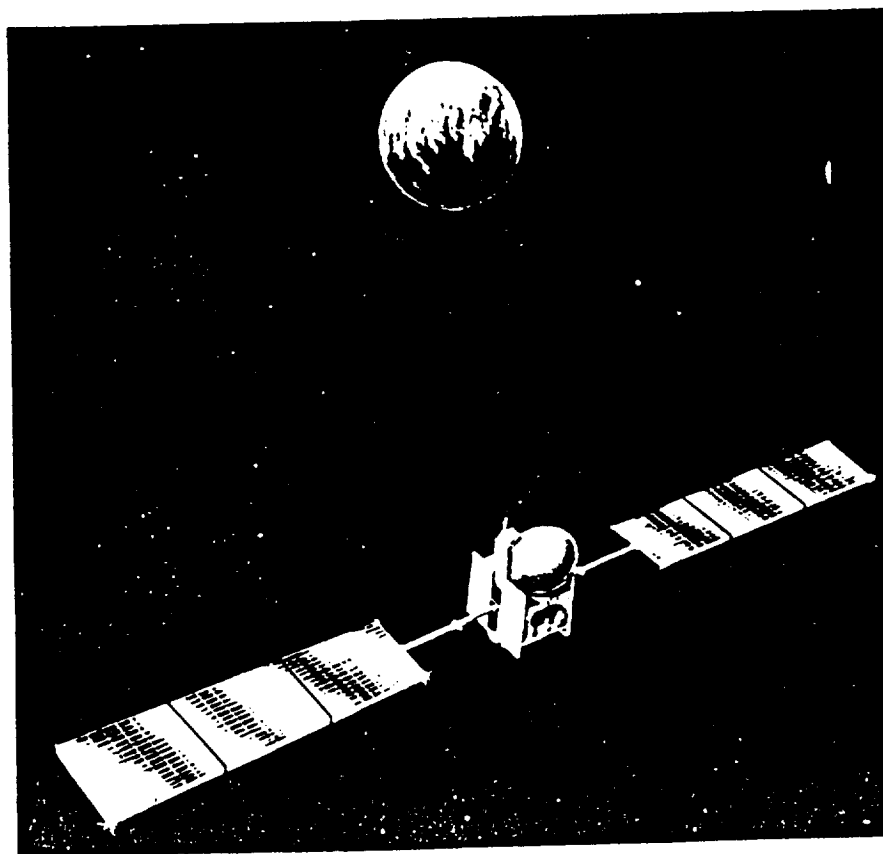
- |                    |                                   |
|--------------------|-----------------------------------|
| • THRUST           | 0.49-0.22 N                       |
| • EXHAUST VELOCITY | $2.9 \times 10^3 \text{ ms}^{-1}$ |
| • POWER            | 550-250 W                         |

#### HYDRAZINE RESISTOJETS (ROCKET RESEARCH)

Electrically-augmented hydrazine thrusters manufactured by Rocket Research are currently operational on RCA SATCOM, G-Star and Spacenet communication satellites. The G-star satellite shown in the photo weighs 670 kg at beginning of life with a solar array power of 1065 W. The SATCOM-K satellite weighs 985 kg at beginning of life with 2000 W of power. The Rocket Research thruster produces a thrust of 0.36 - 0.18 N and exhaust velocities of  $2.74 \times 10^3$  -  $2.98 \times 10^3$  m/s for an electrical power input of 500 - 300 W. This represents a 30 percent increase in performance over that available from conventional hydrazine thrusters which translates into reduced propellant requirement or increased satellite life. Ongoing research at Rocket Research is directed at the achievement of higher exhaust velocities and higher thrust. Future commercial and military communications satellites will be larger and will require higher thrust for N-S stationkeeping. In work sponsored by INTELSAT, Rocket Research has designed and is fabricating a 2.0-N thruster designed to operate at an exhaust velocity of  $3.04 \times 10^3$  m/s and a power of 2.0 kW.



# **JPL** HYDRAZINE RESISTOJETS BUILT BY ROCKET RESEARCH ARE OPERATIONAL ON RCA SATCOM, G-STAR AND SPACENET COMMUNICATION SATELLITES

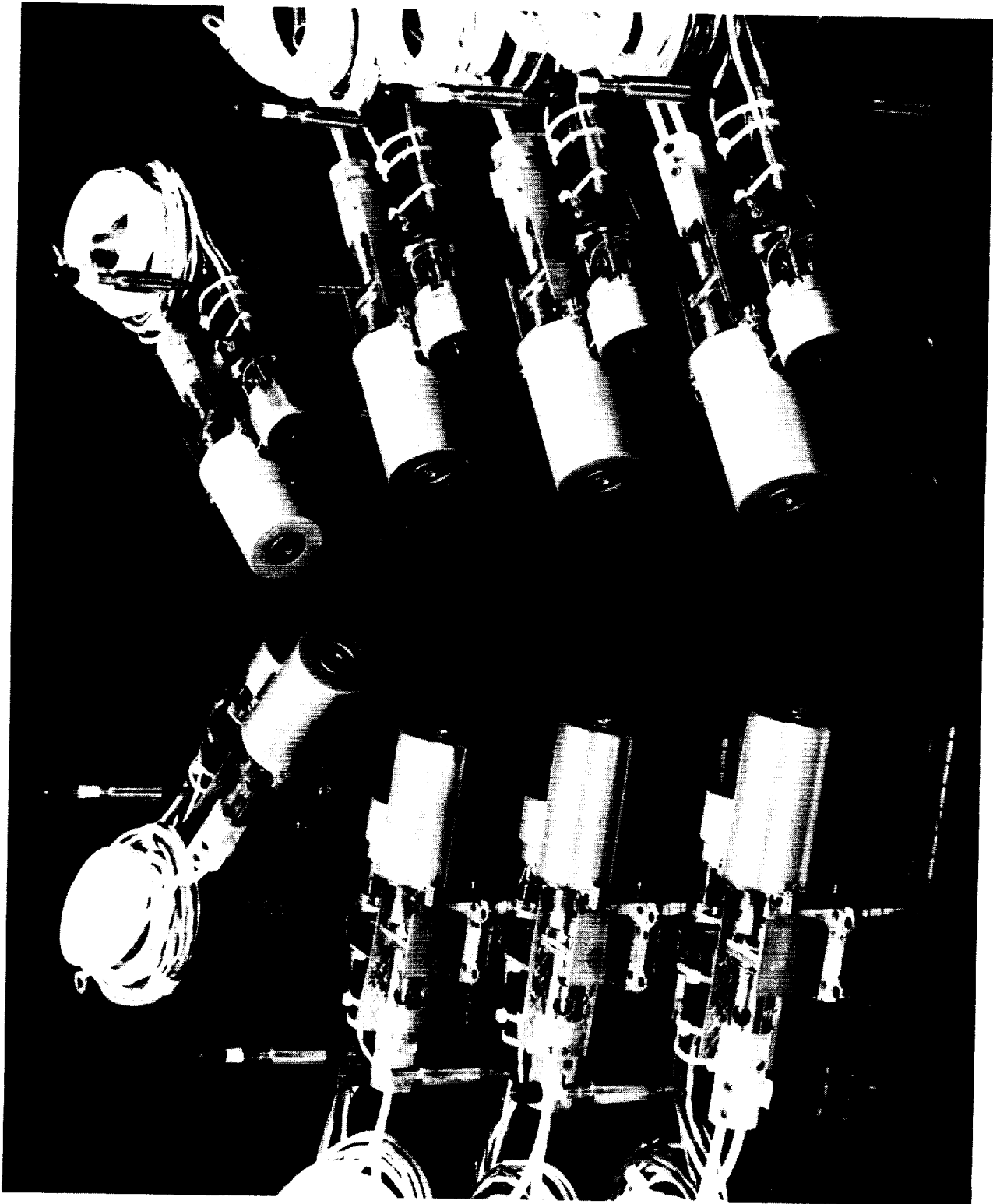


G-STAR

- 3 AXIS STABILIZED
- 10 year LIFE

THRUST	0.36-0.18 N	$\text{ms}^{-1}$
EXHAUST VELOCITY	2.7-3.0 x 10 <sup>3</sup>	ms
ELECTRICAL POWER	500-300	W

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HYDRAZINE RESISTOJETS

#### LOW-POWER ARCJET SYSTEM

Recently, low-power arcjets have been studied for application on the N-S stationkeeping function on communication satellites. Research programs at NASA LeRC, Rocket Research and Purdue University have led to a better understanding of energy loss mechanisms and arc stability. Rocket Research has demonstrated performance of 510 - 550 lbf-s/lbm for a low-power hydrazine arcjet operating at chamber pressures of 60 - 70 psia, thrust levels of 0.045 - 0.052 lbf and an input power of 1300 W. The Rocket Research low-power arcjet system (MR-508) is scheduled for use on a GE AstroSpace spacecraft for the Telstar IV communication satellite. The satellite is scheduled for a 1992 launch.

## LOW-POWER ARCJET SYSTEM

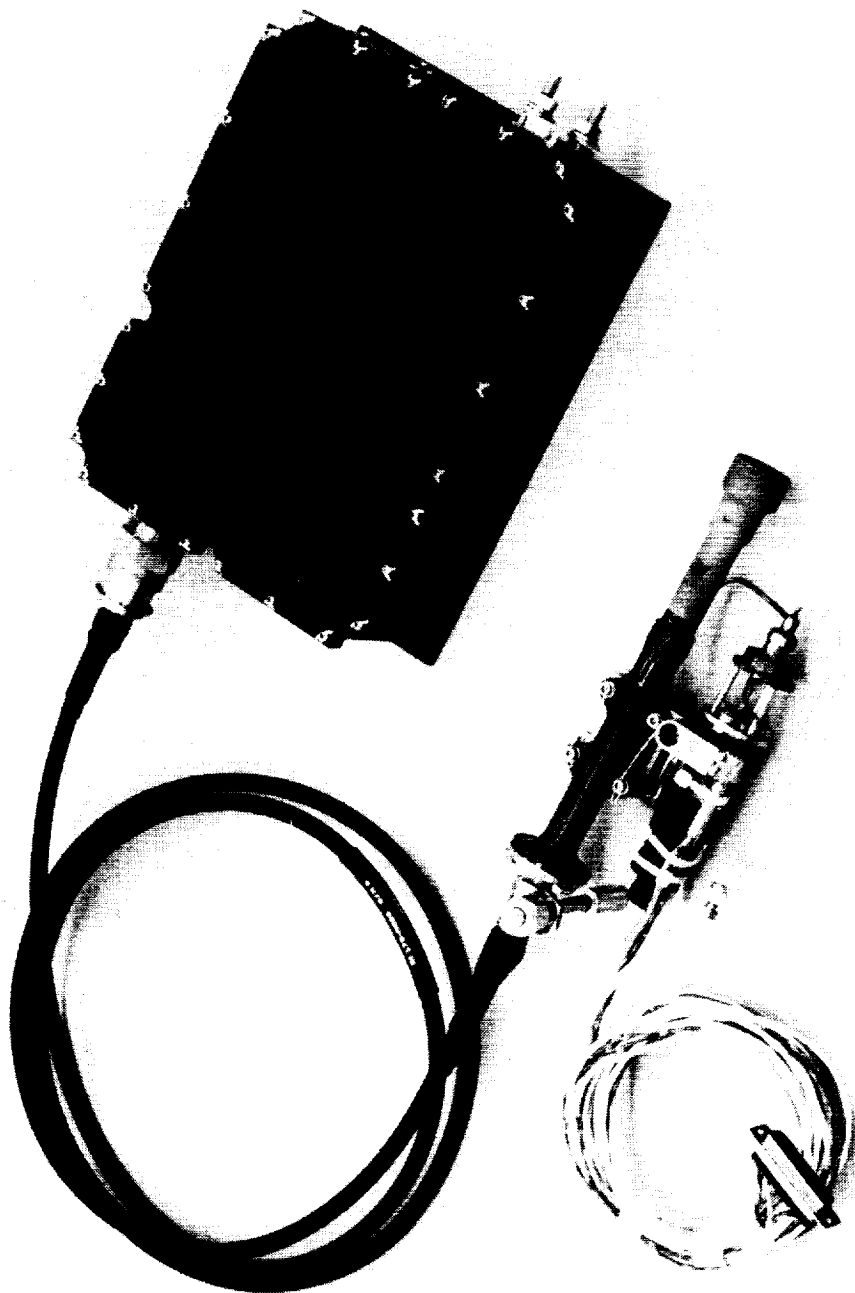
### PERFORMANCE (Rocket Research)

- Hydrazine Propellant
- Thrust: 0.045 - 0.052 lbf
- Chamber Pressure: 60 -70 psia
- Specific Impulse: 510 - 550 lbf-s/lbm

### STATUS

- Rocket Research Low-Power Arcjet is Scheduled for Use on a GE AstroSpace Spacecraft to be Launched in 1992

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**RRC 1.8 KW  
ARCJET SYSTEM**

LOW POWER ARCJETS

#### HIGH-PERFORMANCE ENGINE

Conventional radiation-cooled bipropellant engines utilize disilicide-coated columbium thrust chambers which have a nominal operating temperature of 2400 F. Work on high temperature rhenium thrust chambers was begun at JPL in the mid 1970's as part of the High Energy Propulsion System (HEPS) program. Rhenium permits thrust chamber operating temperatures of greater than 4000 F; however, rhenium has a low oxidation resistance. Since the mid 1980's, NASA LeRC has had a research program looking at high temperature materials and coatings for thrust chambers. Recently, a feasibility demonstration effort has been conducted at Aerojet TechSystems under JPL contract to see if this high performance engine technology could be made available for CRAF/Cassini missions. The demonstration was conducted using a 445-N bipropellant engine (NTO/MMH) with a thrust chamber fabricated from iridium-coated rhenium. The increased bipropellant engine performance (326 lbf-s/lbm) offered by this technology reduces the injected mass requirement for the CRAF mission by more than 600 kg compared with conventional bipropellant engine performance (308 lbf-s/lbm). Although the high performance bipropellant engine technology is not currently being pursued for the CRAF mission, due to lower propulsion requirements, this technology is still being pursued by NASA LeRC and the U. S. propulsion industry.

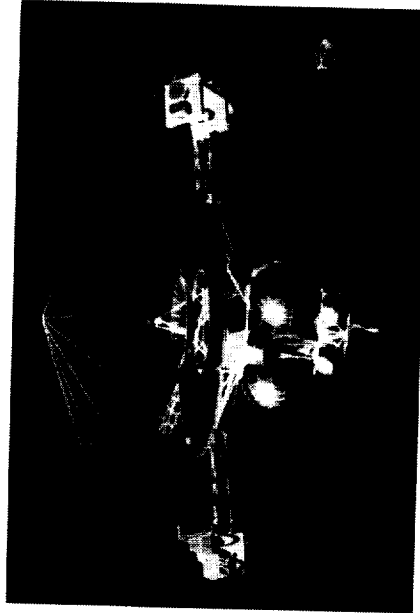
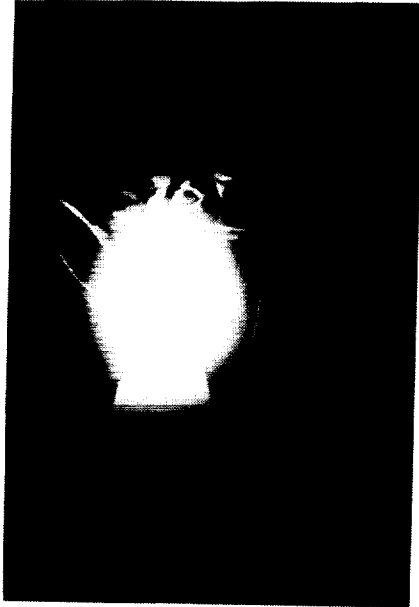
- JPL CONTRACT BUILDS ON LeRC TECHNOLOGY PROGRAM

- $I_{sp}$  IMPROVED TO 326  $lb_f \cdot s/lb_m$

- REDUCES PROPULSION SYSTEM WET MASS ALMOST 600 kg

- ENABLES CRAFT TO ADD 3 EXPERIMENTS

OSSA



OAST

#### DUAL MODE PROPULSION SYSTEM

A dual mode propulsion system offers advantages over conventional spacecraft propulsion systems. The dual mode propulsion system consists of a bipropellant engine (NTO/hydrazine) for the main propulsion function and a monopropellant (hydrazine) engine for the attitude control functions. This arrangement permits the bipropellant and monopropellant engines to share common propellant tankage. The bipropellant engine (NTO/hydrazine) offers higher performance than conventional bipropellant engines (NTO/MMH). As a result, the dual mode propulsion system offers a substantial mass savings over conventional systems. The new propellant combination (NTO/hydrazine) offers plume contamination advantages over conventional bipropellant systems (NTO/MMH) due to the absence of carbon in the fuel. The use of monopropellant hydrazine for attitude control functions also leads to lower contamination.

TRW has been developing a dual mode propulsion system for spacecraft application. The bipropellant engine (NTO/hydrazine) has demonstrated a performance of 313 lbf-s/lbm compared with conventional bipropellant engines with a performance of 308 lbf-s/lbm. The TRW dual mode propulsion system is scheduled for use on the GE AstroSpace Series 5000 spacecraft for Canadian, SES and Intelsat-K communication satellites. The first launch is expected to be the SES satellite in January 1991.

# DUAL MODE PROPULSION SYSTEM

## DESCRIPTION

- Main Propulsion Uses Bipropellant Engine (NTO/hydrazine)
- Attitude Control Function Uses Monopropellant Engine (hydrazine)

## ADVANTAGES

- Higher Bipropellant Engine Performance, Lower Contamination Potential
- Common Propellant Tankage, Lower Propulsion System Mass

## STATUS

- TRW Developing Dual Mode Propulsion System
- Bipropellant Engine Demonstrated 313 lbf-s/lbm
- TRW Dual Mode Propulsion System Scheduled for Use on a GE AstroSpace Spacecraft to be Launched in 1991



## SUMMARY

- Propulsion system performance has high leverage for many future missions because of large propellant mass requirements. Relatively small performance improvements can translate into large increases in payload and science return.
- Contamination control becomes more important as science instruments become more sensitive. This places more emphasis on exhaust plume contamination control.
- The need for reliable operation and long life places increased importance on health monitoring and control of spacecraft propulsion systems.
- The need for accurate spacecraft pointing and control increases the need for small impulse-bit thrusters.



**PROPULSION SYSTEMS OPTIONS-  
NEXT GENERATION SYSTEMS**



PRESENTATION 1.3.1

**SHUTTLE DERIVATIVES - MANNED**

